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A GPS analysis for urban freight distribution

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Abstract

Daily life in urban centers has led to increasing and more demanding freight requirements. Manufacturers, retailers and other urban agents have thus tended towards more frequent and smaller deliveries, resulting in a growing use of light freight vehicles (<3.5 ton). This paper characterizes and analyzes urban freight distribution in order to generate new ways of understanding the phenomenon. Based on a case study of two different-sized Spanish cities using data from GPS, a vehicle observation survey and complementary driver's interviews, the authors propose a categorization of urban freight distribution. The results confirm GPS as a useful tool that allows the integration of dynamic traffic assignment data and diverse traffic operation patterns during different day periods, thereby improving delivery performance.

1. Introduction

There is today a general consensus that cities depend heavily on the harmonious and efficient performance of their transport systems, in which urban freight transport plays a key role. In fact, freight flows comprise about one fourth of street traffic (Dablanc, 2007), and are thus responsible not only for urban traffic, but also for externalities (i.e. undesirable environmental impacts) such as pollution, noise, congestion and accidents (Visser et al., 1999).

The aim of this paper is to develop a consistent framework to characterize urban freight movements, namely those of small freight vehicles or light vans (< 3.5 tons). The research attempts to identify links between the attributes of freight transport routes in the urban area and the company activities related to the kind of goods transported. A cross-survey analysis is performed based on quantitative and qualitative data (a vehicle observation survey, a GPS survey and a complementary vehicle trip diary) and the categorization proposed.

Various studies have highlighted the importance and accuracy of GPS data to improve the reporting of the trip, due to the high precision of the data obtained in this way (Murakami et al., 1999); however, few analyses have been carried out based on this system. Thus the main contribution of this paper is to provide a case study analyzed using data from GPS systems.

2. Research design

The study of urban freight distribution is defined, within its special circumstances, as basic research (the knowledge generated has no direct practical application) since it aims to:

- Investigate the relationship between the variables that characterizes the urban movement of goods.
- Diagnose any findings revealed by this method, such as the relationship between accidents and vans (MIFO, 2008).
- Test and adapt other international research to the Spanish case.
- Create new ways to understand the phenomenon of urban freight distribution.
- Build or adapt tools for measurement, namely the GPS tool.

Within the types of research design through to development level for the topic in this paper, the present case can be classified as exploratory research (as opposed to a descriptive or explanatory design), for the following reasons:

- It examines a little-studied research topic, which will give rise to various questions not previously addressed, at least in Spain.
- There is little literature on the subject.

This study therefore focuses on an in-depth analysis of urban freight distribution, rather than on the description or measurement of certain variables with a high degree of statistical rigor. The scope of this paper is to synthesize, describe, outline and identify the topic, rather than to measure and clarify. This is done by means of an exploratory research based on a qualitative analysis with a number of unique features:

1. It is inductive (Rubin and Babbie, 2008). The aim is to show that when phenomena and processes of urban distribution of goods are regularly repeated, then some property can be assumed to explain it.
2. It is a holistic approach. The urban freight distribution is a whole which differs from the sum of each of its parts or agents (Russo and Comi, 2010a):

- Those who must take decisions (public authorities, private companies, public-private partnerships).
- Those who have to abide by them (end-consumer, receivers, shippers, wholesalers).
- Those linked through the logistics system (producer-wholesaler, wholesaler-retailer, producer-retailer).

3. Qualitative research in transport simultaneously uses multiple data sources and data collection instruments. The numerous different survey techniques that have been used in recent urban freight studies (Allen and Browne, 2008) include:

- Establishment survey
- Commodity flow survey
- Freight operator survey
- Driver survey

- Roadside interview survey
- Vehicle observation survey
- Parking survey
- Vehicle trip diaries
- GPS survey
- Supplier survey
- Service provider survey

For our research purposes, quantitative data were needed on: number of stops, average speed, distance between stops, duration of each stop, etc. The authors therefore studied the viability of using the innovative GPS tool to obtain this information. Exploratory research also requires qualitative data obtained from vehicle trip diaries and the vehicle observation survey, as will be described further on.

4. In order to characterize the urban distribution of goods from the three types of data discussed above (vehicle observation survey, GPS survey and vehicle trip diaries), triangulation of data was used, where the size of the sample is defined up to saturation point (Wilson, 2003) in order to find redundant information.

The *saturation point* is used in qualitative studies to determine whether to continue interviewing or, in our case, taking data from drivers' behaviour. This theory is based on the principle of the variability of the informant's opinions. If there is not much variability, a small sample should be enough. Since a GPS analysis is not cheap, it was very important to establish a research design whose validation could be carried out with a small sample.

3. Methodology

The first step was to define the tools to be used for the exploratory research into urban freight distribution by type of goods (vehicle observation survey, GPS survey and vehicle trip diaries), to establish the categories of routes to consider, and then to identify a set of indicators to be applied to two Spanish cities (Fig. 1.).

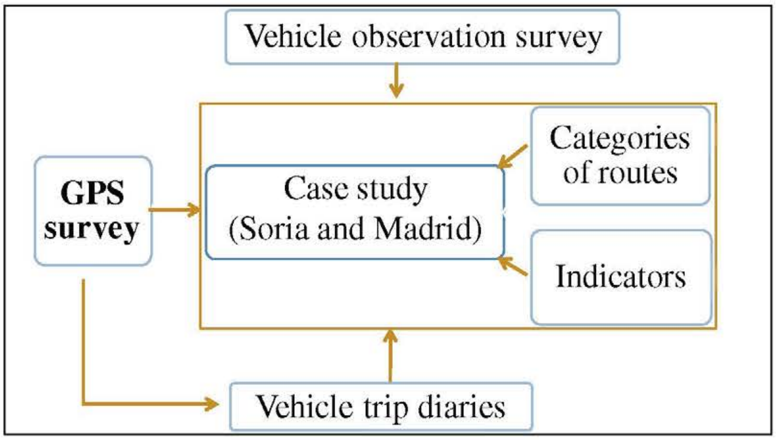


Fig. 1. Research methodology

3.1. Route classification

Categorization of urban freight vehicles is based on the following five route classifications:

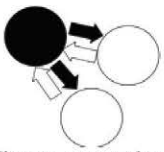
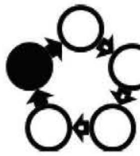
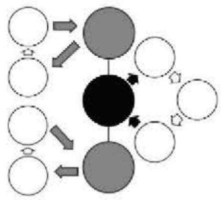
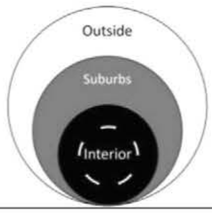
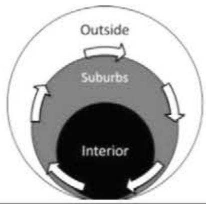
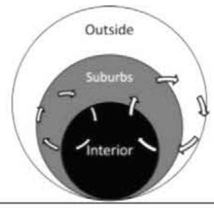
I: Spatial distribution of tours	I.a. Centralized  The van constantly returns to a single warehouse. I.b. Decentralized  The van starts from the warehouse and then stops at several nodes along the journey; finally, at the end of the journey it returns to the warehouse (i.e. starting point). I.c. Mixed 
II: Who defines the route	• II.a. By company: The van follows routes which are previously determined by the company. • II.b. By driver: The van follows routes which are constantly defined by the driver based on traffic, environmental conditions and demand.
III: Temporal patterns	The van has a routine that repeats: • III.a. daily • III.b. every day of the week • III.c. each season • III.d. no pattern
IV: The productive use of van	Rate between time in movement and time stopped. • IV.a. Low • IV.b. Medium • IV.c. High
V: The relative origin/destination location	V.a. Inside  V.b. Outside  V.c. Mixed 

Fig. 2. Categorization according to different route classifications

3.2. Indicators

Using the information provided by GPS data (quantitative), observation surveys and the responses derived from the vehicle trip diaries (both qualitative) the following indicators are defined in order to characterize the routes:

Table 1. Indicators according to route classification

Classification	Indicator	Value	
I: Spatial distribution of tours			
I.a. Centralized	Number of *tours*	≥ 2	
I.b. Decentralized	*(supported by the qualitative analysis of the GPS-data interface)*	1	
I.c. Mixed	Existence of several key locations	-	
II: Who defines the routes			
II.a. By company	Answer to the question of vehicle trip diary: *Who defines the route?*		
II.b. By driver			
III: Temporal patterns			
III.a. Daily	Answer to the vehicle trip diary question: *What kind of routine do you have?* (daily, weekly, seasonalor no routine at all)		
III.b. Weekly			
III.c. Seasonal			
III.d. No pattern			
IV: The productive use of the van	*(Performance indicator)*		
IV.a. High		<1	
IV.b. Medium	$\frac{D_t}{T_s} = \frac{\text{Driving time}}{\text{Time stopped}}$	≈1	
IV.c. Low		>1	
V: The relative origin/ destination location		(small city)	(big city)
V.a. Inside	Average distance between stops	< 2 km.	< 5 km.
V.b. Outside	*(complemented by the qualitative analysis of the GPS-data interface)*	> 2 km.	>5 km.
V.c. Mixed	Study of the deviation of the average distance between stops	-	-

4. Case study: Soria and Madrid, two Spanish cities

According to the Ministry of Public Works (MIFO, 2008), the province of Madrid has the largest registered fleet of vans in Spain (668,892). By contrast, excluding Ceuta and Melilla, the province with the lowest number is Soria (14,354). Since the objective of the research is to make a representative analysis, it was necessary to conduct the study in Soria and Madrid so as to enable comparison of two cities with diametrically opposing van fleets.

In order to have precise and complete information on urban freight movements it was decided to base the study on three different survey techniques:

- Vehicle observation survey: survey or real-time observation to draw some initial conclusions about the urban freight transport in Spain according to type of vehicle and goods.
- GPS survey: this tool provides data on vehicle location at frequent intervals, route information, and speed.
- Vehicle trip diary: used to supplement information not provided by the GPS data, in order to evaluate some of the indicators previously described.

Before presenting the results of the investigation, the data collection process must be explained.

4.1. Vehicle observation survey

This is based on the direct observation of traffic density at several points in two different-sized cities. The total size of the sample was about 40,000 vans, and the date chosen for the count was the second half of June 2009.

It was decided that the most suitable time to conduct the surveys was from 7 am to 7 pm at all points (FUNDACIÓN MOVILIDAD, 2008). The data were taken at intervals of 10 minutes, but it was later decided to group the results every half hour. Each control point was surveyed for two days in order to observe possible deviations, and two checkpoints were set up in the small town (Soria) and five in the big city (Madrid) in order to provide representative data.

Following the statistical methodology until the point of saturation was reached, vans passing by each control point were counted according to the type of goods (Allen et al., 2000): (i) construction, (ii) food, (iii) courier, (iv) newsagent, (v) furniture, (vi) services and (vii) others, for all remaining goods. In the early days of data collection, a large proportion of unidentified vans (white vans) were observed, and a group of auxiliary goods was therefore added with the name: (viii) unidentified.

4.2. GPS technology

To obtain more accurate information about the topic considered (urban freight movements) it was decided to use GPS technology. Given the high cost of this kind of approach, the sample consisted of 20 light vans followed during two months (February and March 2010). A GPS N-AUTO PLUS®, a commercial model commonly used as a control measure for fleets, was installed on the vans. As economic reasons meant the sample could not be too large, the types of goods from the observation vehicle survey were reorganized so all unidentified vans were considered as self-employed. Thus, the following five groups were established:

1. Courier group: stationery store, bookstore, furniture store and express service.
2. Food group: catering trade, butchery, supermarket and restaurant.
3. Service group: urban services, sanitation, laundry.
4. Construction group: repair shop and construction company.
5. Self-employed group: self-employed carrying all types of goods, but usually building materials.

Fig. 3. Examples of van delivery routes for the mail group in Madrid: Wednesday, March 17(a) and March 24(b)

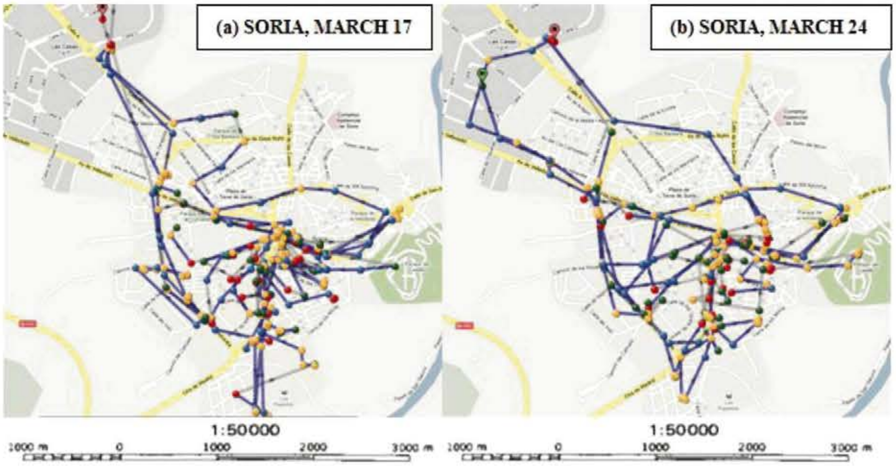


Fig. 4. Examples of van delivery routes for the mail group in Soria: Wednesday, March 17(a) and March 24(b)

The process of obtaining information about route attributes consists of measuring precisely the movement variables for each vehicle, and for this purpose we installed GPS systems in ten light vans in each city. A graphic interface (Fig. 3 and Fig. 4) then allows this huge amount of data to be visualized and analyzed, and the results are described.

4.3. Vehicle trip diaries

Qualitative information was obtained by performing a personalized diary survey to supplement the GPS data (Ohmori et al., 2006), enabling the evaluation of some indexes described previously. It consists of two relevant questions, both representative of movement:

- Who defines the route? (driver or company).
- *What kind of routine do you have?* (daily, weekly, no pattern).

Both questions are necessary to evaluate indicators II and III (Table 1) respectively.

5. Results

5.1. General mobility patterns

The results of the vehicle observation survey help to set the general mobility patterns of urban freight distribution in Spain, and will contribute to further research (Fig. 5).

First, the difference between the unidentified group in Soria and in Madrid is quite large, with a 23.96% increase in Madrid. These differences could be justified through many assumptions, from higher car use for private transport purposes in Madrid, to a greater number of carriers or self-employed persons using unmarked vehicles for different reasons. Another group which was identified but not included in the remaining categories, i.e. others, is also significantly higher in Madrid than in Soria. This is because in Madrid there is greater economic activity and a greater demand for different types of goods.

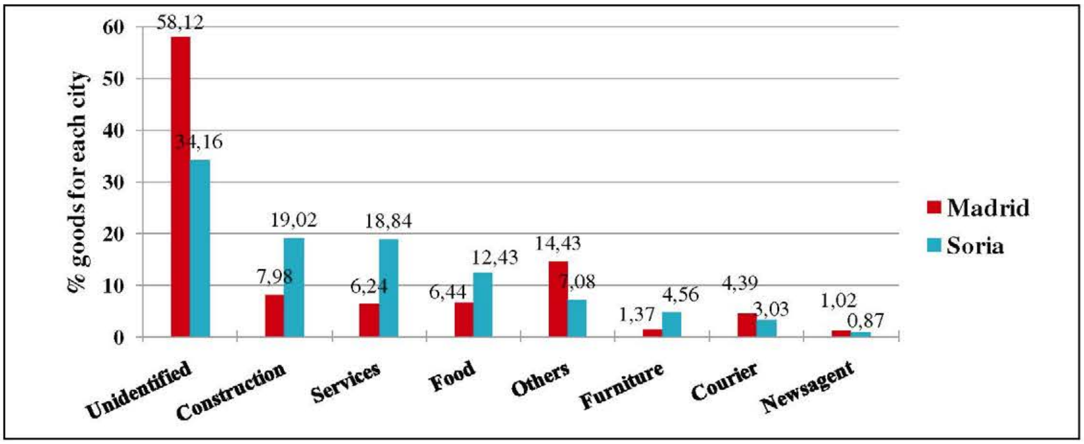


Fig. 5. Classification by type of goods (vehicle observation survey)

An analysis of the number of vans counted by time of day (Fig. 6 and Fig. 7) reveals a more uniform distribution in Soria, whilst in Madrid there are clear peak hours in the morning (10 am-2 pm) and off-peak hours by around 3 pm. Other European studies place the busiest period at 6 am-12 pm (Browne et al, 2010), but, as can be seen, urban mobility in Spain takes place at different time periods.

The following figures show a comparison of vans counted at two checkpoints with similar characteristics in each city. Fig. 6 shows the comparison of two checkpoints located inside the cities (Calle Goya, Madrid; and Plaza Mariano Granados, Soria). The number of vans counted is very similar despite the different size of the cities. Moreover, commercial activity starts earlier in Soria (8 am) than in Madrid (9 am).

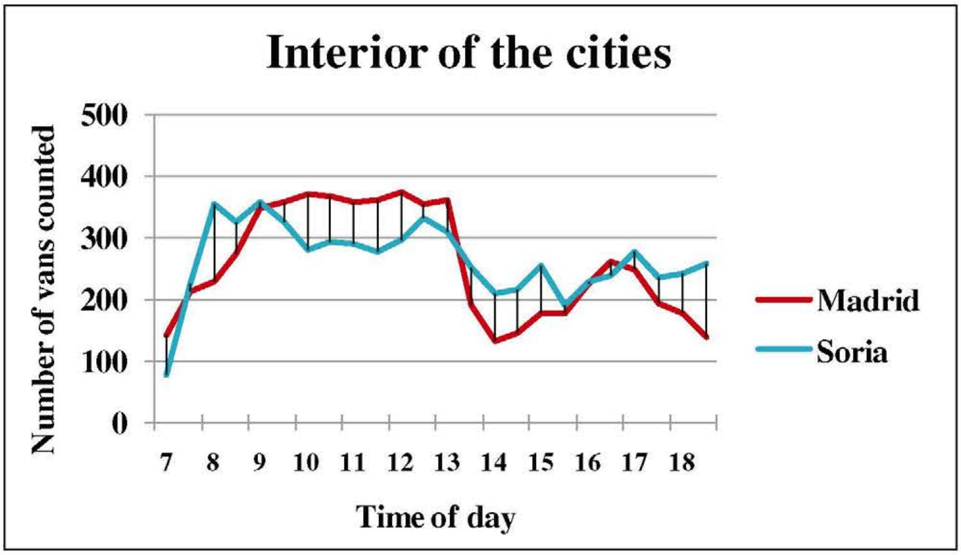


Fig. 6. Comparison of the total number of vans counted at two different checkpoints situated in the interior of the cities

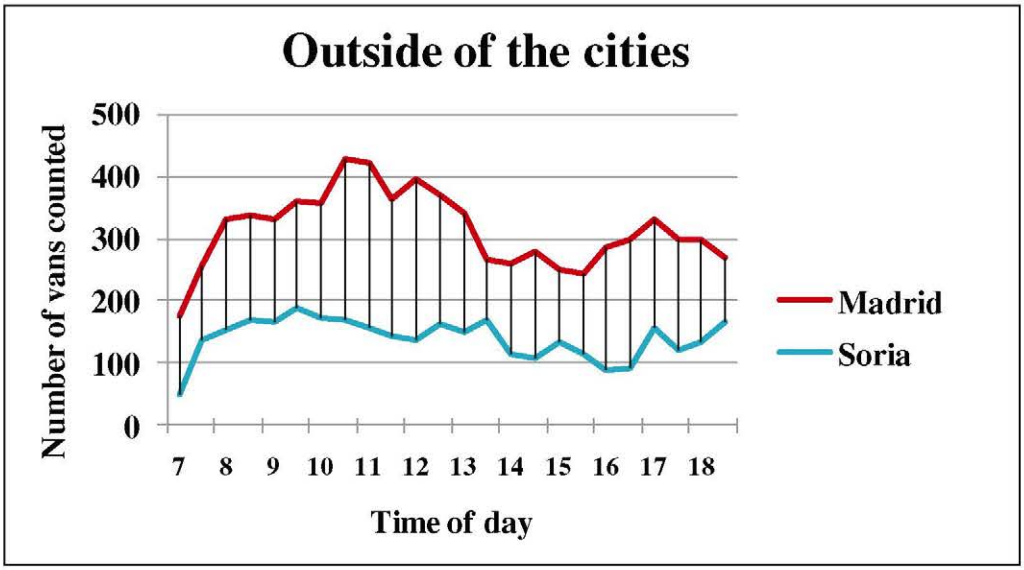


Fig. 7. Comparison of the total number of vans counted at two different checkpoints situated outside the cities

Checkpoints in the two industrial zones located on the outskirts of the cities (Avenida de Oporto, Madrid; and Avenida de la Constitución, Soria) indicate greater commercial activity in Madrid. The number of vans in Soria is very homogeneous throughout the day. In Madrid, peak hours are 11 am and 5 pm.

5.2. GPS data

The results of the GPS study, by type of goods, were found to be similar in both cities (Tables 2 and 3). Since all results are provided by the GPS, it is important to note that they should not be treated in the same way as those provided by a survey. For example, the number of stops/day is the number of times that the driver stops the van, but the driver may make a delivery with the engine still running. It is also necessary to distinguish between stop and delivery, as one stop can serve several deliveries.

Table 2. Results of the GPS data, Madrid

Freight category	Stops/day	Stop length/day		Distance between stops/day		Use of van/day:
		average (min)	st.deviation	average (km)	st.deviation	*(driving time/ time stopped)*
Courier	43.6	8.8	*5.3*	1.8	*2.7*	0.6
Food	5.1	22.5	*14.0*	15.3	*19.5*	0.8
Service	8.1	11.6	*1.9*	10.6	*3.6*	2.5
Construction	12.6	23.4	*17.8*	12. 0	*11.0*	1.0
Self-employed	13.9	35.3	*20.2*	12.9	*2.7*	0.7

Table 3. Results of the GPS data, Soria

Freight category	Stops/day	Stop length/day		Distance between stops/day		Use of van/day:
		average (min)	st.deviation	average (km)	st.deviation	*(driving time/ time stopped)*
Courier	31.3	7.3	*10.7*	0.9	*1.0*	0.7
Food	10.7	10.7	*8.3*	20.3	*23.6*	1.9
Service	8.2	16.1	*3.7*	3.9	*2.2*	1.0
Construction	8.8	19.2	*37.8*	7.2	*1.5*	1.2
Self-employed	8.8	14.8	*9.3*	7.3	*8.5*	1.2

The courier group seems to be an exception among the quite homogeneous indexes reported in Table 1 for the rest of the groups. For example, the number of stops/day is 43.6 and 31.3 in Madrid and Soria, respectively, but in the other cases this value is on average 10. On the other hand, the food group has high day-to-day variability (see the columns for average stop length and average distance between stops). Conversely, the service group shows almost no variation over the test days.

The construction and self-employed groups present the most important differences between both cities. Since Madrid is a large city with greater economic activity than Soria, vans transporting construction materials (it should be noted that these items are often carried by the self-employed) make more stops per day, and the average length and distance between stops are higher in Madrid than in Soria.

Regarding the use of the van, the values are higher in Soria than in Madrid. As Madrid is a more congested city than Soria and has a greater economic activity, the vans spend more time stopped than in movement. This fact determines the *use of van* indicator as an index of sustainability, since it relates the time taken by a van to move from one delivery to another with the time taken for each delivery. A group-by-group analysis shows that the courier group is the most sustainable, i.e., more efficient and less polluting.

5.3. Cross-survey analysis

To analyze the main characteristics of urban freight mobility in two contrasting cities in Spain, we also carried out a disaggregated analysis of urban and light freight vehicles. This permitted the categorization and analysis of urban freight mobility based on qualitative (vehicle observation and interviews) and quantitative (GPS data) information. This was done by developing star-shaped-graphics for each city and type of goods, as follows (Fig. 8 and Fig. 9).

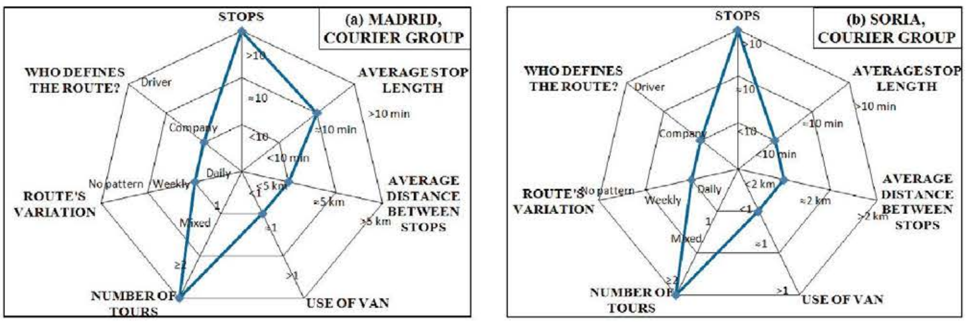


Fig. 8. Urban freight categorization of the courier group: Madrid(a) and Soria(b)

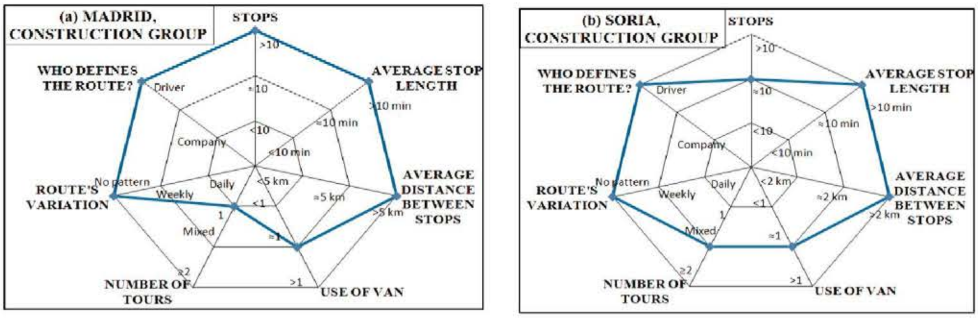


Fig. 9. Urban freight categorization of the construction group: Madrid(a) and Soria(b)

The best performance in qualitative terms is for both the courier and construction groups, since both groups provide most homogeneous quantitative (through GPS) and qualitative (through interviews) data, hence making the comparison easier. The performance of both food and service deliveries is clearly more difficult to explain, since it shows more statistical deviations than the groups mentioned above. This case reveals that the indicators with the most relevant results are those provided by the GPS according to the route classification, which show that both the daily pattern and a pre-defined route (by the company) reduce stop lengths. Furthermore, there is a correlation between this indicator and the distance between stops.

The average stop length and the average distance between stops in the courier group are lower than in the construction group. For this reason, there are more stops and tours in the first group (courier).

Some European studies have pointed out that whatever the city (its geography, its regulations, etc.), deliveries will be made in a more or less similar way (Dablanc, 2007). In this study, Fig. 8 and Fig. 9 confirm this finding since the star-shaped-graphics by type of goods are very similar. General characteristics can therefore be established regardless of the size of city.

Finally the information presented must be crossed. Following the route classification shown in Table 1, we can understand the links between homogeneous patterns of behaviour by type of goods as follows (Table 4):

Table 4. Results of the cross-survey analysis

CATEGORIES / GROUPS	I. Spatial distribution of tours	II. Who defines the routes	III. Temporal patterns	IV. Use of the van	V. The relative O/D location
A. COURIER	b. Decentralized	a. By company	a. Daily	a. Low	a. Inside
B. FOOD	b. Decentralized c. Mixed	b. By driver	b. Each day week c. Each season	b. Medium	b. Outside c. Mixed
C. SERVICE	a. Centralized c. Mixed	a. By company b. By driver	a. Daily d. No pattern	b. Medium c. High	a. Inside b. Outside
D. CONSTRUCTION	c. Mixed	b. By driver	c. Each season d. No pattern	b. Medium	b. Outside
E. SELF-EMPLOYED	c. Mixed	b. By driver	d. No pattern	b. Medium	c. Mixed

The main group-by-group conclusions are:

- Courier group: this group presents a large number of short and quite concentrated stops. Consequently, as these vans frequently remain stopped, the *use of van* indicator (driving time/time stopped) is lower in comparison to the other groups. This implies that this group is potentially the one which most hinders the *other* activities involved in urban mobility, but is more efficient because it carries out a greater number of deliveries. The routes, which are usually concentrated in the interior and predefined by the company, present daily patterns.
- Food group: this group presents weekly patterns whose routes are defined mainly by the van drivers. This group appears to be the most heterogeneous one. Indeed, contrary to the rest of the groups, GPS data show an important variability across the vans. This group is therefore more difficult to categorize and analyze.
- Due to this generalization, our findings should be carefully interpreted and may be inappropriate to this case; further research should focus solely on this group.
- Service group: this group is dominated by routes in the interior of the city, which are predefined by public companies. The tours are centred on a base, and present a low number of stops.
- Construction group: this group has no repeating pattern. Moreover, the routes are improvised and set by the van drivers. Depending on the duration of the repair work or building work –usually located on the outskirts of the city– driving behaviour is more or less particular to each driver.
- Self-employed group: this group presents routes similar to those of the construction group. The van is used for mixed use (travelling home for lunch, going shopping, picking up the children from school, etc).

6. Conclusion

Using a real data set we have analyzed the main characteristics of urban freight mobility in two contrasting cities in Spain. We have carried out a disaggregated analysis of urban and light freight vehicles. We have also studied the case of the autonomous group (self-employed), as its presence in Spain is significant. We have thus been able to categorize and analyze the urban freight distribution based on qualitative (vehicle observation survey and interviews) and quantitative (GPS data) information.

According to Russo and Comi's proposed city logistics measures (2010b), GPS technology can be considered as non-material infrastructure measures. GPS data make it possible to effectively evaluate how and where to introduce a city logistics policy on which to base, for example, the allocation of loading/unloading bays, support vehicle routing and scheduling according to the degree of congestion on the transport network, and in order to promote the exchange of information among actors.

The research results have made use of GPS to draw results that could not have been obtained solely with a survey. Policy changes could therefore address a much broader range than in this report if there were a better understanding of the special circumstances in which urban freight delivery tales place. The main objective of this paper is therefore to serve as a basis for future, more specific and precise studies, aimed to quantify and model the movement of trucks in the cities (Comendador et al, 2011).

However, the general conclusions are:

- The vehicle observation survey results revealed a very considerable percentage of unidentified vehicles (*white vans*). Numerous self-employed workers use the van as a vehicle to carry different types of goods (or for mixed use), which adds another layer of complexity to the problem of urban freight distribution, since in Spain there is no regulation in this regard. Nevertheless, since 20 September 2010, all self-employed persons wishing to register their vans must include the *activity code* (IAE in Spain).

- With regard to the time of deliveries, *peak times* (morning peak, afternoon peak and off-peak hours) can be seen in big cities, whilst in smaller cities the use of vans is more uniform throughout the day.
- By type of goods, the mobility of vans by size of city does not make a significant difference.
- The *use of van* performance indicator (driving time/time stopped) measures the sustainability of the urban freight distribution. The GPS data makes possible to know the productivity or efficiency of a van. A value of *use of van* less than or equal to 1 means that the van's driver spends more time delivering than polluting and consuming fuel, making it therefore more *sustainable*.
- For future research, the author strongly recommends studying the particular case of urban freight mobility of companies involved in food transport, since it has proved very difficult to establish homogeneous characteristics for this group due to the large differences in mobility when dealing with vans for the retail trade or for major supermarkets.

Acknowledgements

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